Langley Research Center

Hypersonic Inflatable Aerodynamic Decelerators (HIAD) Technology Development Overview

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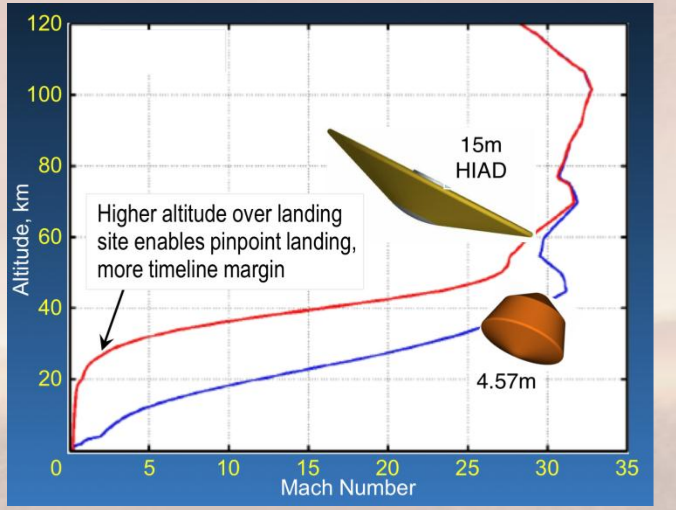
Outline

- Motivation and Background
- Project Organizational Structure
- Flexible System Development (FSD)
  - Thermal Protection Systems (TPS)
  - Inflatable Structures (IS)
- Advanced Entry Concepts (AEC)
- Flight Projects
- Conclusions and Future Work

Motivation for HIAD

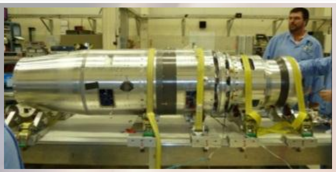
- Aeroshell size limited by Launch Vehicle fairing
- Mars thin atmosphere makes it difficult to decelerate large masses and limits accessible surface altitudes. Science payload size and site altitude are limited by Viking EDL architecture.
- Improved payload access
- After inflation, HIAD behave much like a rigid device. Aerodynamics are scalable. HIAD are lighter, increasing delivered payload.
- Lower ballistic coefficient from increased drag area allows higher altitude deceleration (aerocapture or entry) providing access to higher surface elevations, increase in landed mass, and longer EDL timelines.
- Crewed EDL at Mars can benefit from reductions in ballistic coefficient.

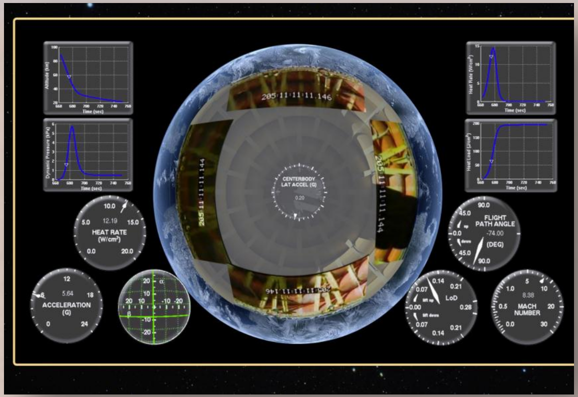
MSL in Launch Vehicle Fairing
(http://marsprogram.jpl.nasa.gov/msl/multimedia/images/?ImageID=3684)



MSL	HEART
3300 kg	3500 kg
4.5 m Dia	8.5 m Dia
125 kg/m^2	40 kg/m^2

Vision for HIAD Mission Infusion





Reentry Vehicle

Sub-scale Aeroshell

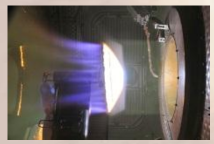
Con Ops

Sub-scale HIAD Flight Test

FLIGHT

GROUND

Mission Infusion



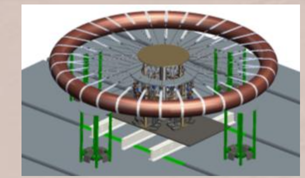
Sub-Scale and Component Level FTPS

Full-Scale FTPS

Sub-Scale and Component Level IS

Full-Scale IS

Aerodynamic Ground Test of Full-Scale HIAD



HIAD Organization Structure

HIAD PI: Neil Cheatwood
PM: Mary Beth Wusk
HIAD CE: Steve Hughes
LaRC

Partnerships: Government Agencies, Industry, Academia

Subject Matter Experts LaRC, ARC, GRC, JSC, GSFC

1.0 Project Management
LaRC

3.0 Advanced Entry Concepts
DPI: Henry Wright
LaRC

- Mission Applications
  Lead: Dave Bose
  LaRC/JSC/MSFC
- Next Gen Subsystems
  Lead: Karl Edquist
  LaRC/JSC
- HEART
  Lead: Henry Wright
  LaRC/JSC

4.0 Flexible Systems Development
FSD PM: Monica Hughes
DPI: Anthony Calomino LaRC

- Flexible TPS
  Lead: Joe Del Corso (2012)
  Lead: Scott Splinter (2013)
  LaRC/GRC
- Inflatable Structures
  Lead: Keith Johnson
  LaRC/ARC

5.0 Flight Validation
LaRC

- IRVE-3
  PM: David Gillman
  CE: Robert Dillman
  LaRC/GSFC (WFF)
- IRVE-3 BTP
  Lead: Lee Noble
  &
  John DiNonno
  LaRC/GSFC (WFF)

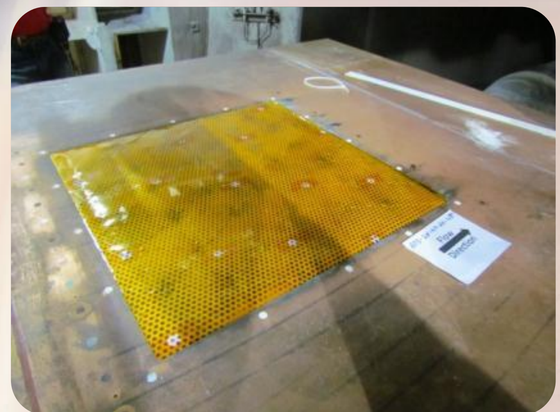
FSD Flexible TPS Development

- **Mission Simulation Testing**
  - LaRC 8-Ft High Temperature Tunnel (HTT)
  - JSC Test Position 2 (TP2)
  - Boeing Large Core Arc Tunnel (LCAT)
- **Materials Testing and Characterization**
  - Age Testing
  - Thermal Conductivity as a function of temperature and pressure
  - Permeability as a function of pressure
  - Strength
  - Pyrolysis/Decomposition Characterization of the insulating materials
  - Emmisivity of outer fabric materials
  - Surface Catalycity of outer fabric materials
- **Physics Based Modeling**
  - CFD to generate ground test environment to simulate flight environment
  - Analytical Thermal Response Model Development

Flexible TPS Mission Simulation Test Facilities

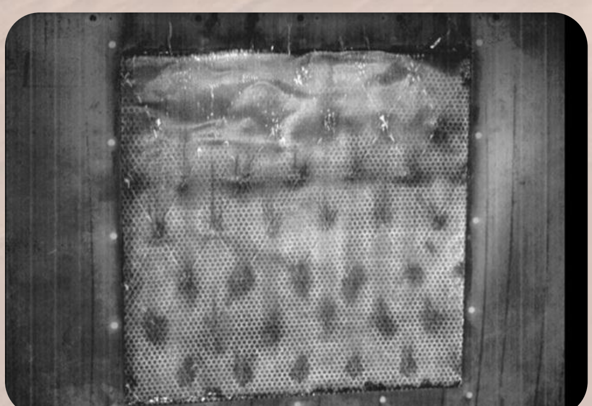
8-Ft High Temperature Tunnel

Toroid Simulator

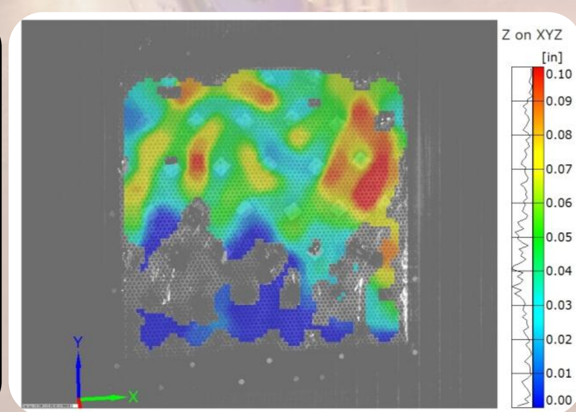


Loaded Sample

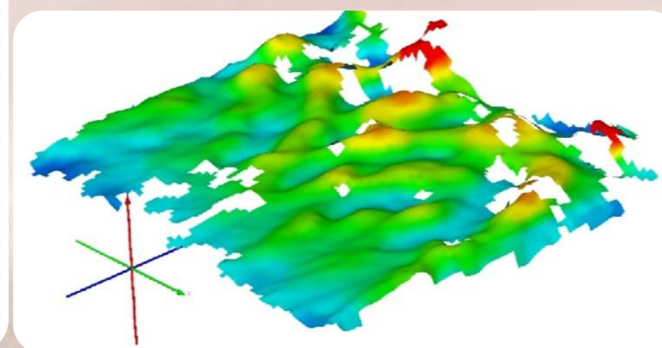
Sample in Run



High Speed Video



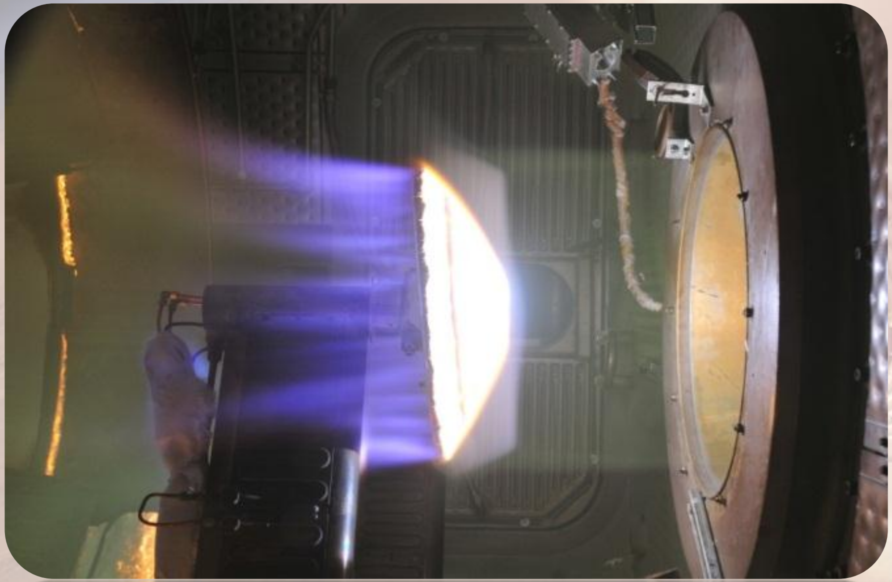
Photogrammetry



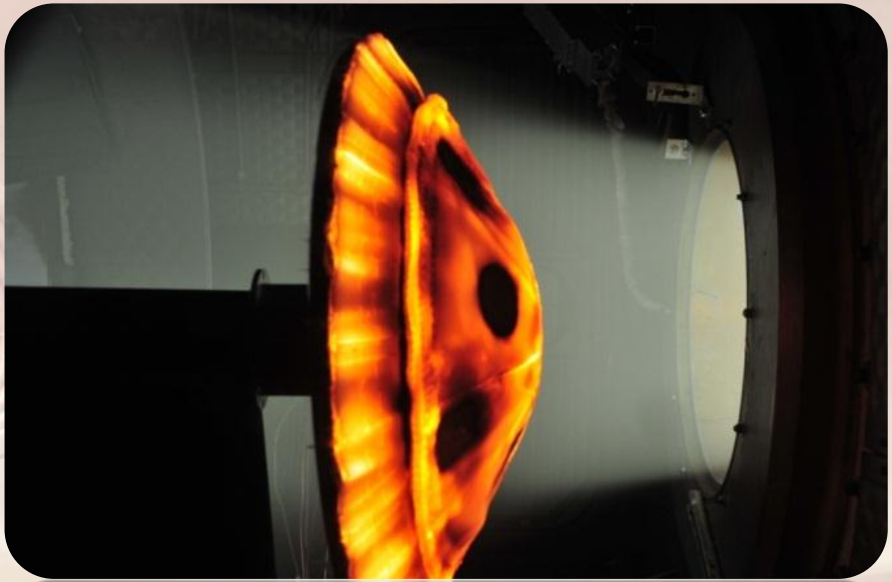
Sample Deflected Surface

Flexible TPS Mission Simulation Test Facilities

JSC TP2 IRVE-3 Nose Cap



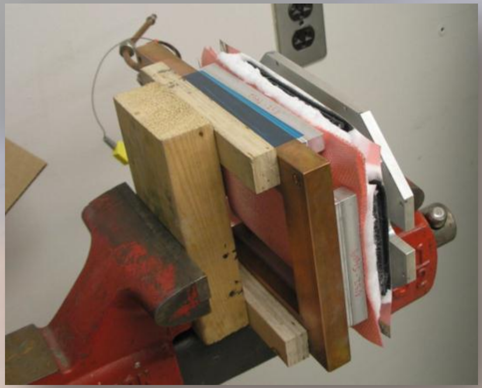
In Flow



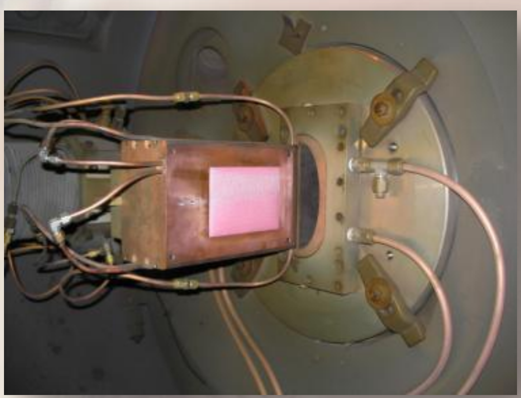
Extracted

Flexible TPS Mission Simulation Test Facilities

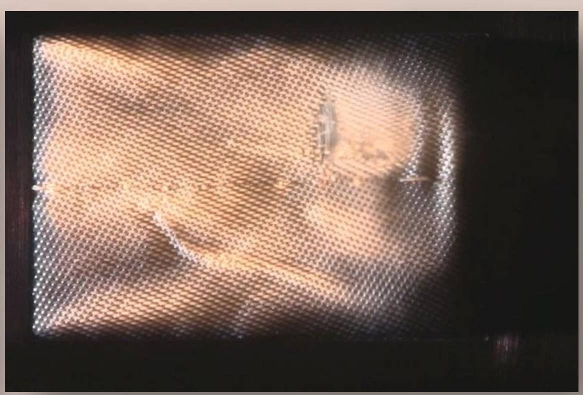
LCAT Shear Testing Development



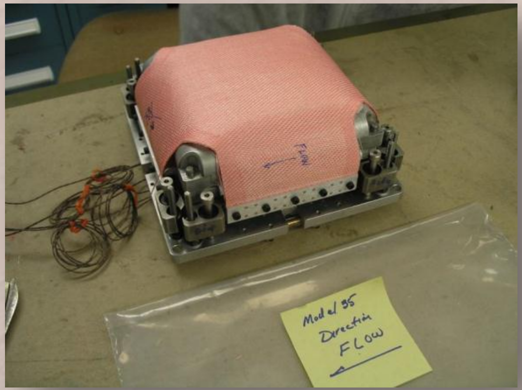
V1.0 Pressed in Sample Holder



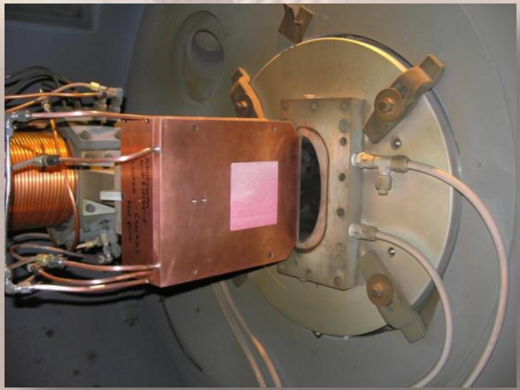
6x4 in Test Cabin



Sample Wrinkling in Flow



V2.0 Mounting 4x4 Configuration

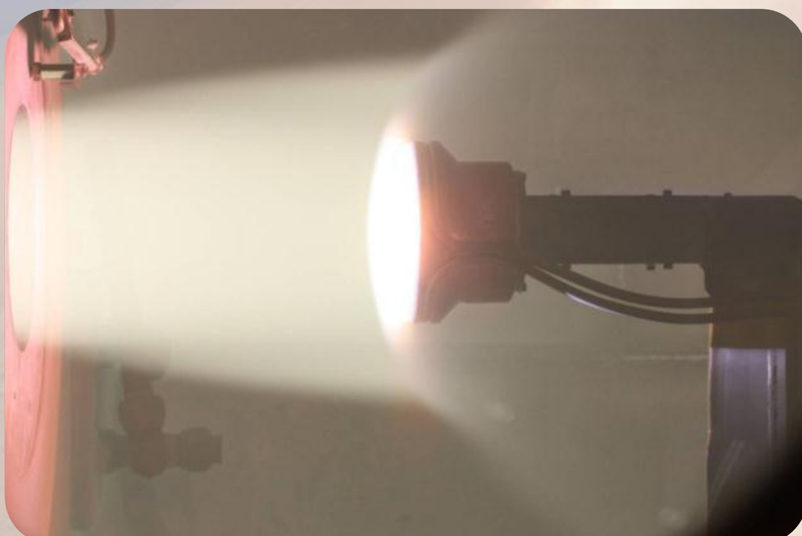


4x4 in Test Cabin

New Sample In Flow

Flexible TPS Mission Simulation Test Facilities

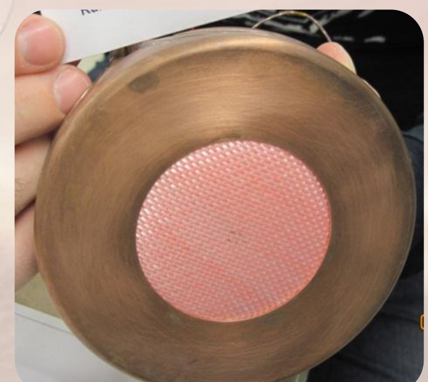
LCAT Stagnation Testing Development



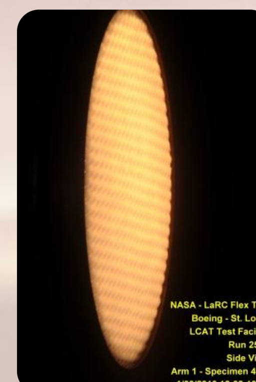
Stagnation Model Holder on Sting

3.5in Holder

In Test



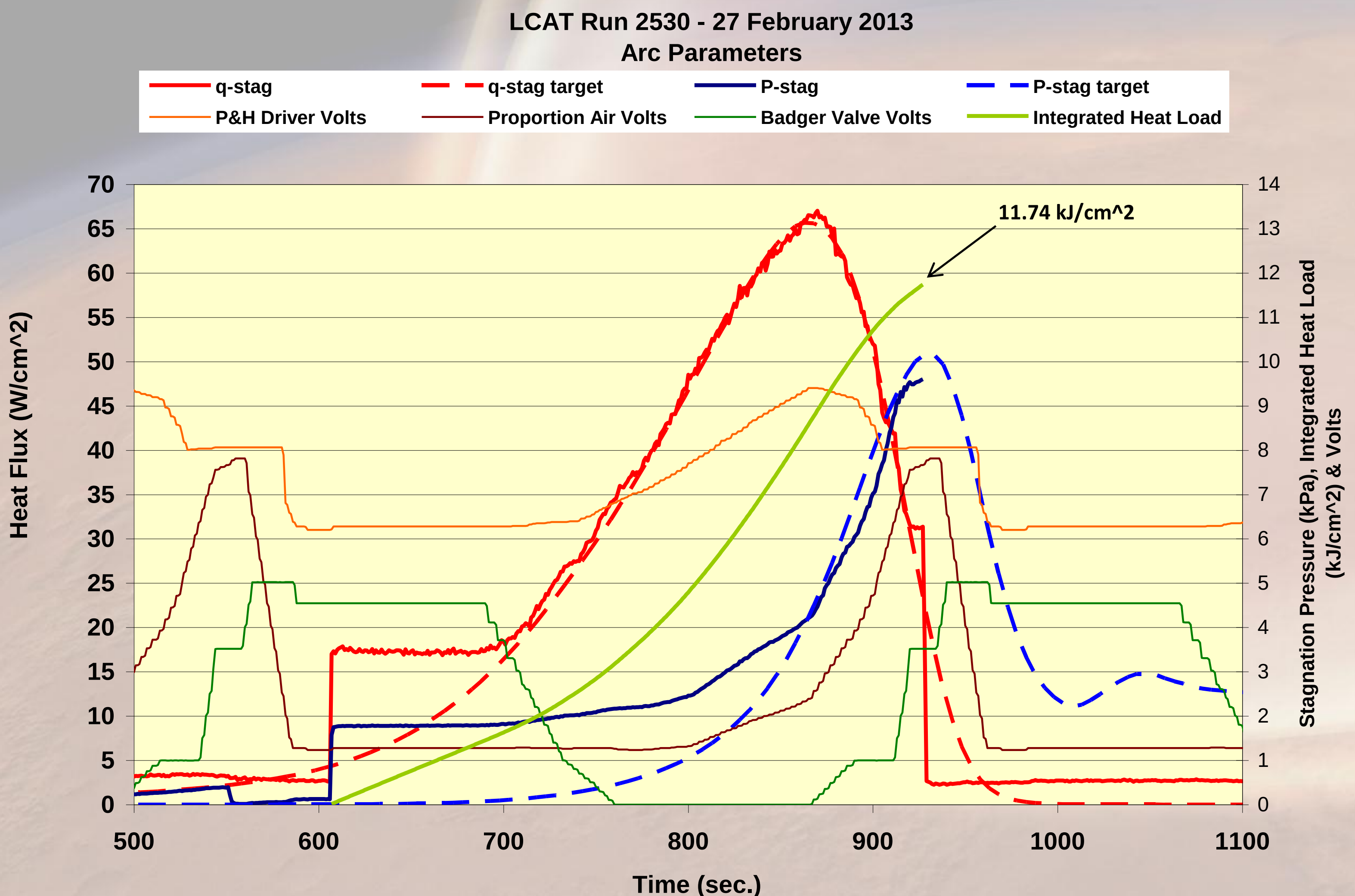
4.5in Holder



In Test

Note: Exposed sample surface is the same for both holders

Flexible TPS Mission Simulation Test Facilities

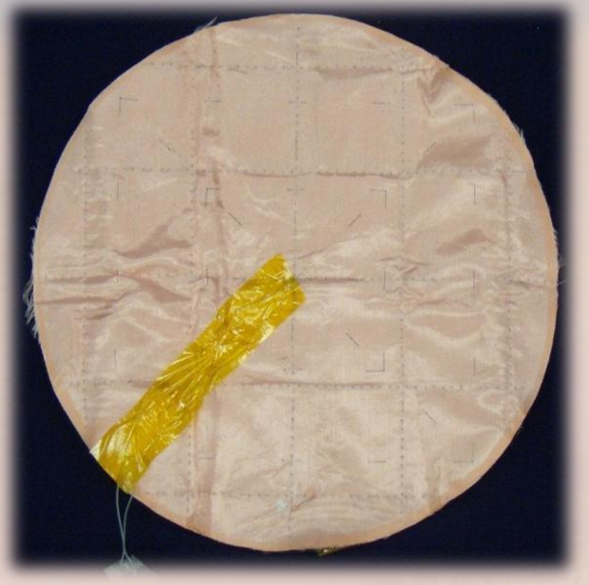


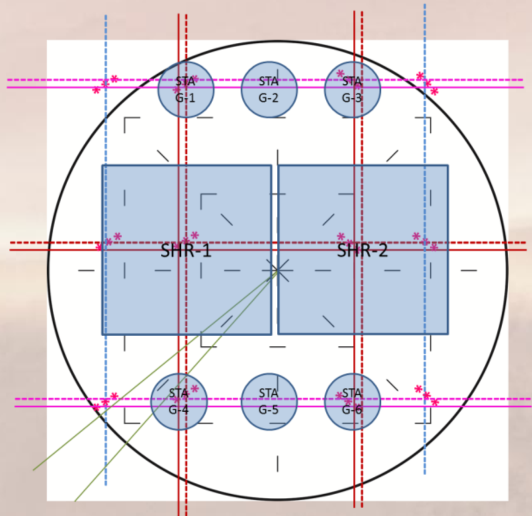
Conceptual Mission Profile Testing at LCAT

FTPS Age Testing

FTPS Age Testing at Southern Research Institute

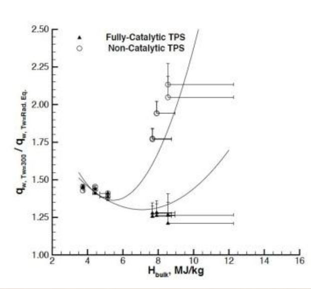
- **Develop Packing/Aging Configuration**
  - Determine achievable packing density
  - Pack/Deploy
  - Thermal cycle
  - Sample extraction
    - Material Properties samples
    - Aerothermal performance samples
- **Material properties determination (Pre-Aged/Post-Aged)**
  - Thermal Conductivity as a function of temperature and pressure
  - Permeability as a function of pressure
  - Strength
  - Pyrolysis/Decomposition Characterization of the insulating materials
  - Emissivity of outer fabric materials



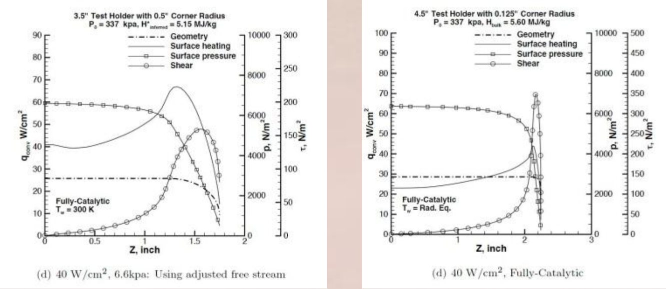


FTPS Physics Based Modeling

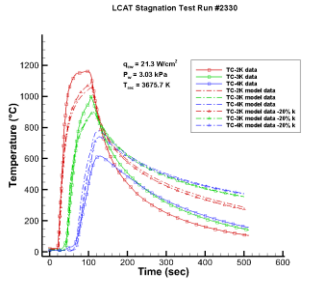
- CFD
  - Determine Environment from Key points along a trajectory simulation
    - Design environment/system requirements for Flight Articles
    - Development of test facility conditions that simulate flight environment
  - Evaluation of Test sample configuration
  - Evaluation of sensitivity of environment to OML distortion
  - Prediction of aft body heating
- COMSOL thermal response model
  - Integration of all material properties
  - Coupled with Monte Carlo Analysis including property uncertainties



Flight Environment to Facility Environment



Model Holder Geometry Evaluation



LCAT Layup Thermal Response Analysis

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FSD Inflatable Structure

- **Manufacturing processes**
  - Elemental Components
  - Stacked Torus Assembly
  - High Temperature Materials
- **Material structural response properties**
  - Load testing at temperature
  - Elemental testing
    - Straight Beam Testing - University of Maine
    - Torus Testing - Dryden Flight Research Center
- **Performance testing**
  - NFAC 6m and 3m
  - Modal Testing
  - Packing durability testing
- **NFAC In-test measurements**
- **Computational Fluid Dynamics (CFD) simulation**
  - NFAC pressure distribution
  - Flight
- **Finite Element Analysis (FEA)**
  - Incorporate Material Property Testing Data
  - Correlation with test data
    - Elemental article tests
    - Static load
    - Aerodynamic Loading
      - NFAC
      - IRVE-3

Manufacturing processes

6m Stacked Torus

Zylon Braid

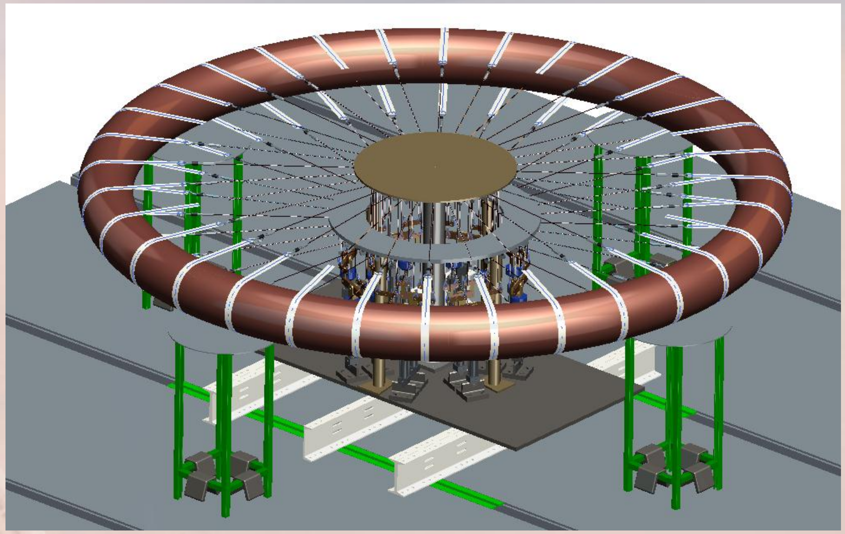
Axial Cord Marking

Straight Beams

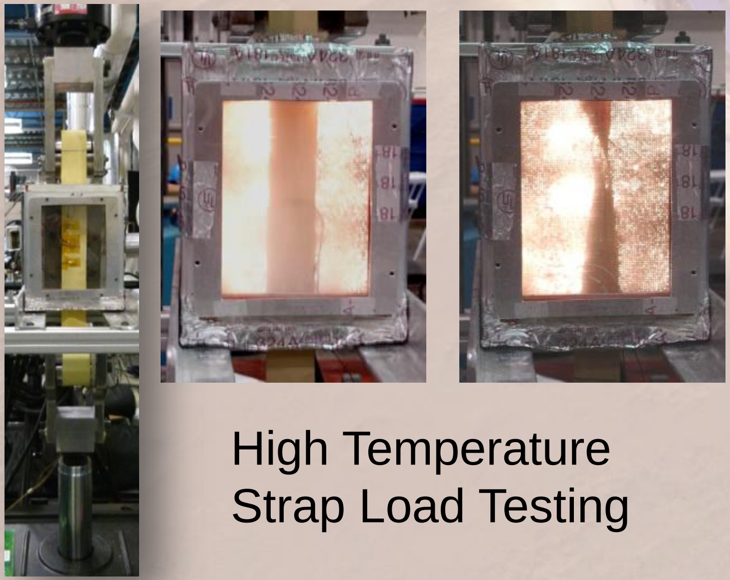
Graphite Braid Torus

Material Structural Response Properties

4-Point Beam Bending



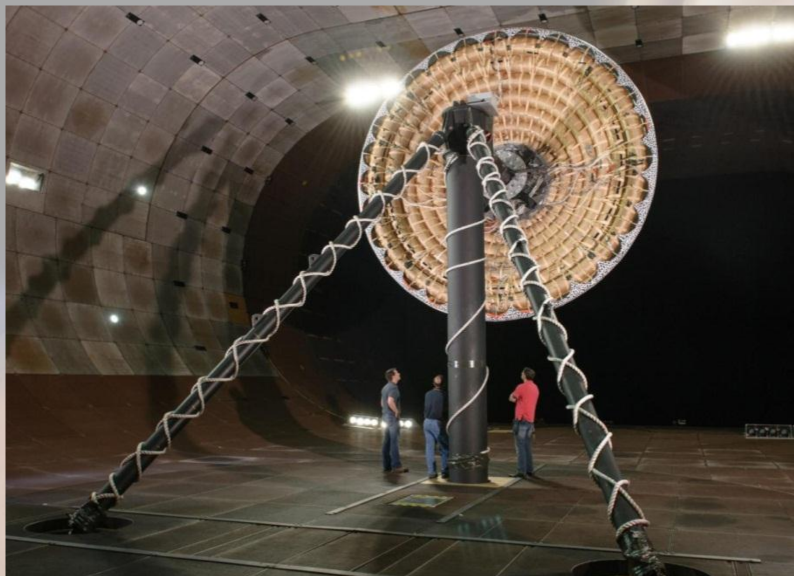
Torus Testing



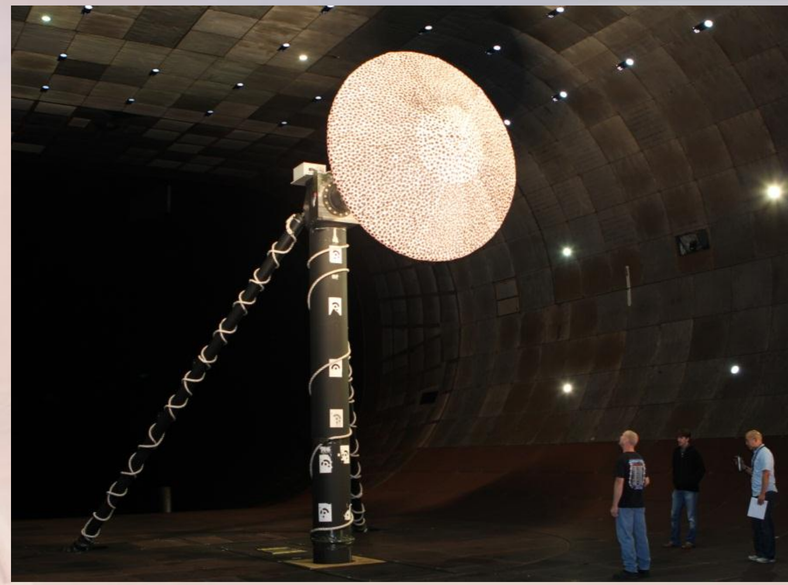
High Temperature
Strap Load Testing

Axial Cord Testing

Performance testing



6m NFAC Test



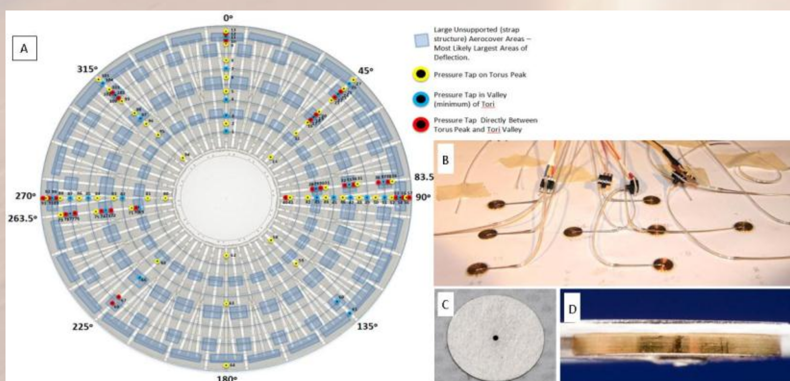
3m NFAC Test

6m Modal Test

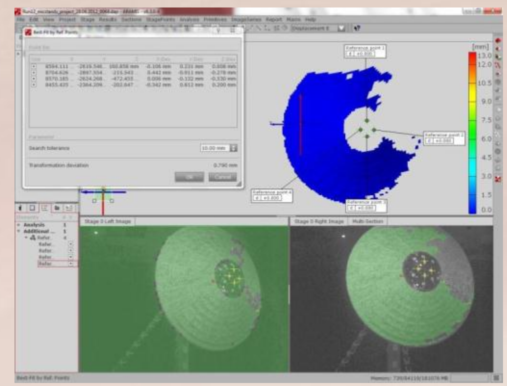
Packing Durability Graphite Torus

NFAC In-Test Measurements

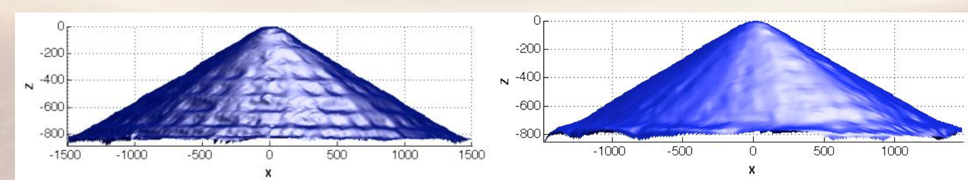
NFAC Strap Load Cell Pins and Buckles



NFAC Aeocover Pressure Taps

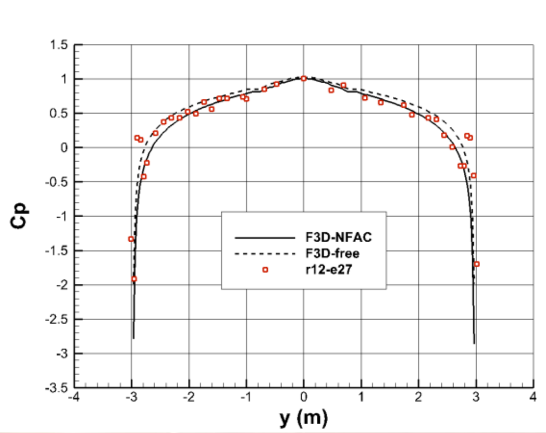


NFAC Aramis Photogrammetry

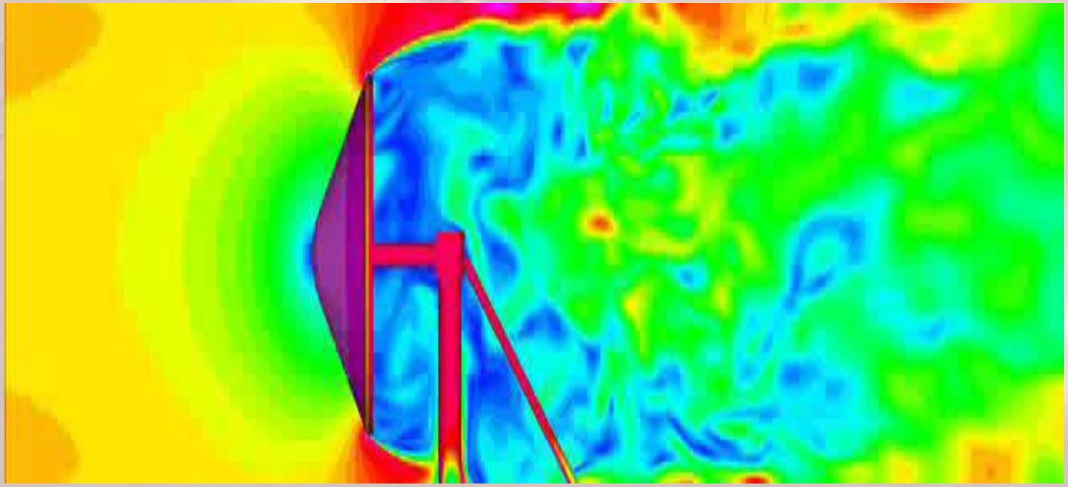


Photogrammetric Solution 3m
NFAC 80PSF Aerocover and TPS

IS Computational Fluid Dynamics (CFD) Simulation

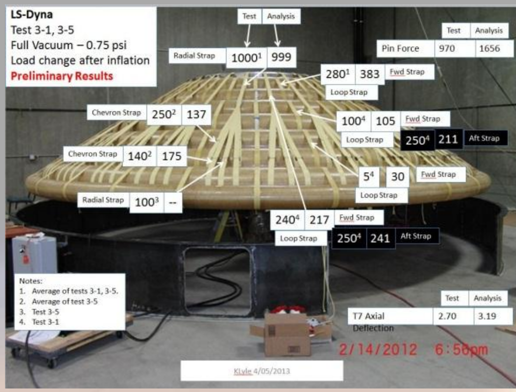


NFAC 6m smooth body CFD compared to aerocover pressure taps

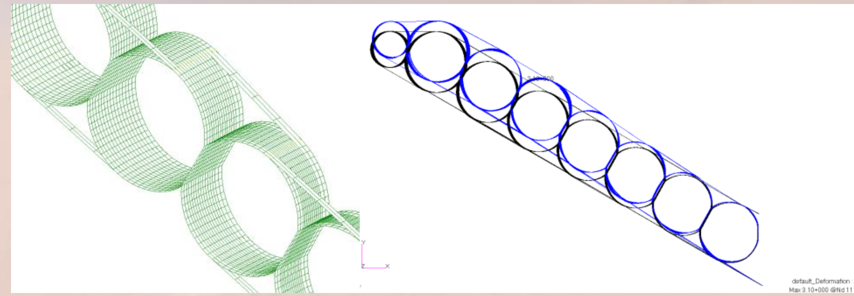


6m smooth body CFD in NFAC 40 x 80

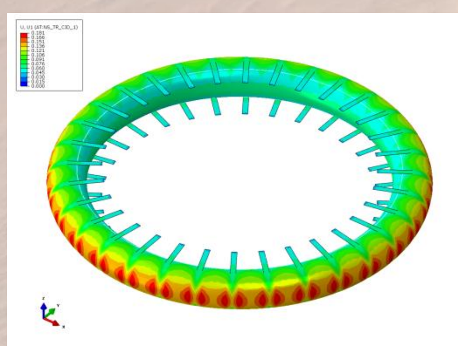
Finite Element Analysis (FEA)



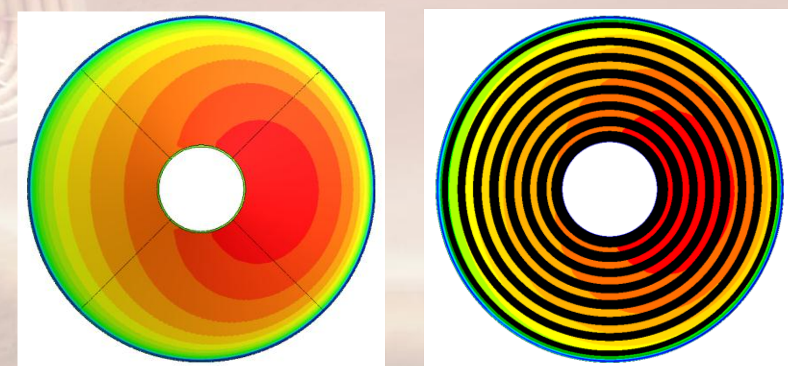
6m IS Static Load Test
LS Dyna prediction vs. strap load test data



Nastran wedge model



Elemental Test Article Radial Loaded Torus
32 Straps, 15 psi, ≈8320 lbf Radial Load

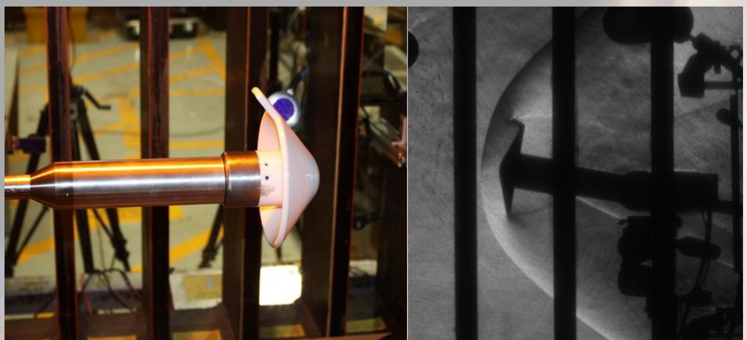


Mapping CFD pressure distribution to annular surfaces on the structural model to analyze structural response to aero load

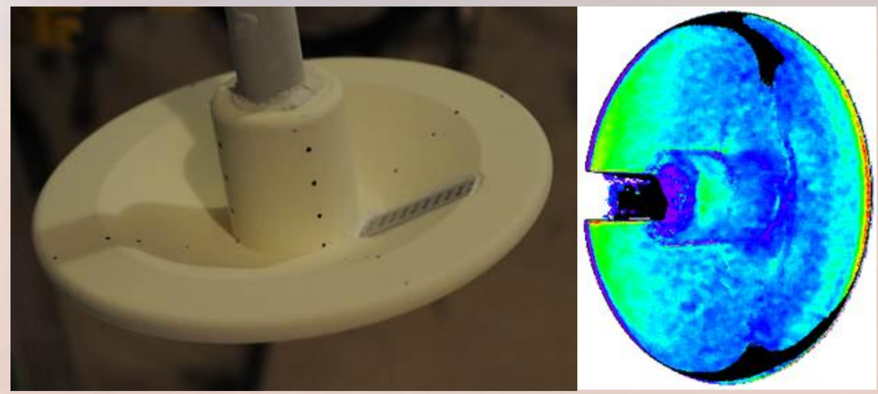
Mission Application Trade Studies

- **Systems analysis has demonstrated HIADs to be applicable to a wide range of mission classes. Potential benefits include:**
  - Launch vehicle asset recovery
  - Expanded landing site access
  - Simplified concept of operations
  - Reduced aerothermal loads
- **High energy entries including some human scale scenarios at Earth required very large HIADs to reduce heating to current flexible TPS performance capabilities.**
  - An increase in flexible TPS performance will significantly increase the range of HIAD applications
- **Future HIAD Mission Applications work shall include:**
  - Investigate HIAD applicability to missions exploring alternative destinations including Venus, Titan and Uranus
  - Complete a deep-dive design and analysis cycle into select Mars Southern Highlands design points to provide full systems view of HIAD integration and verify trade space models

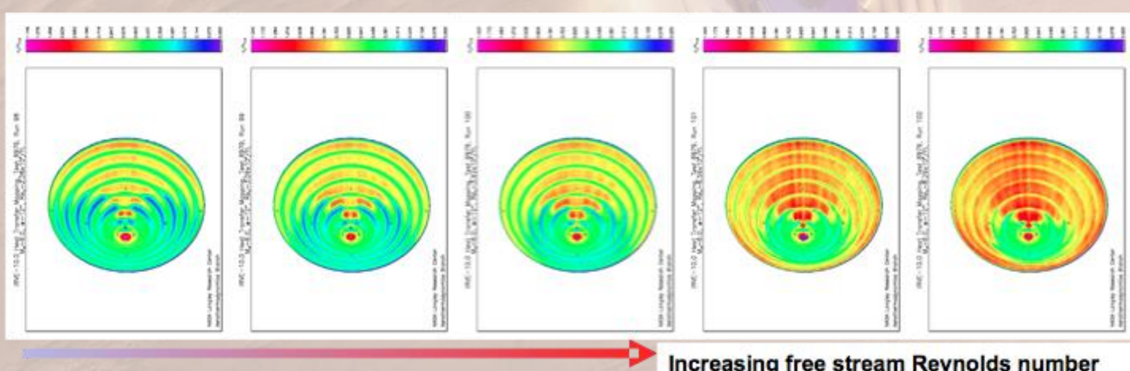
AEC – Next Generation Subsystem

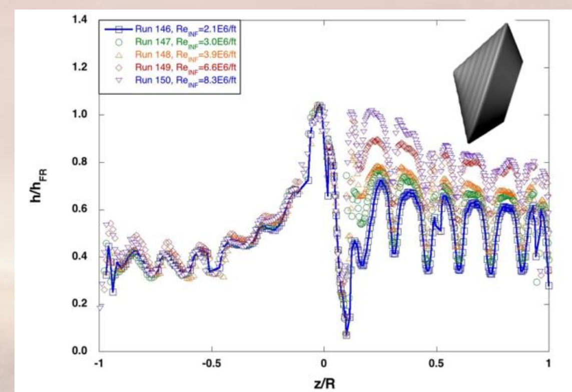


Trim Tab Investigation UPWT



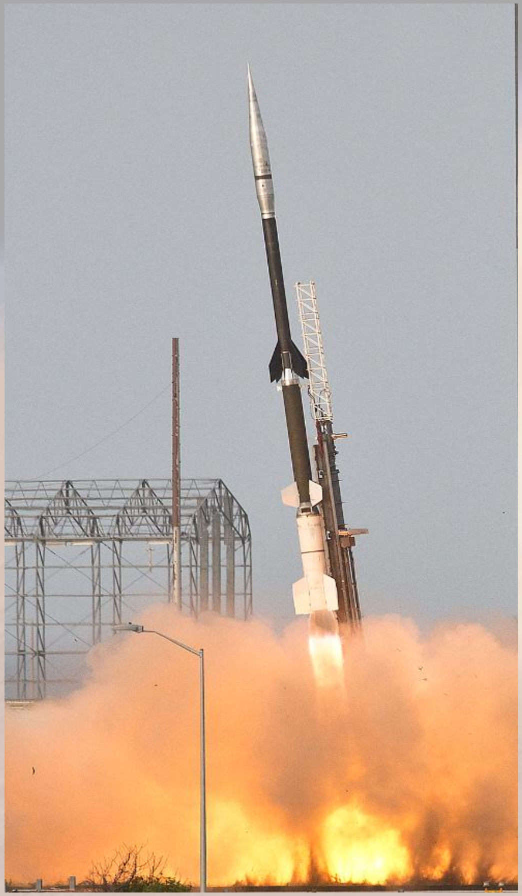
Aft Body Heating Investigation 20in Mach 6 Air



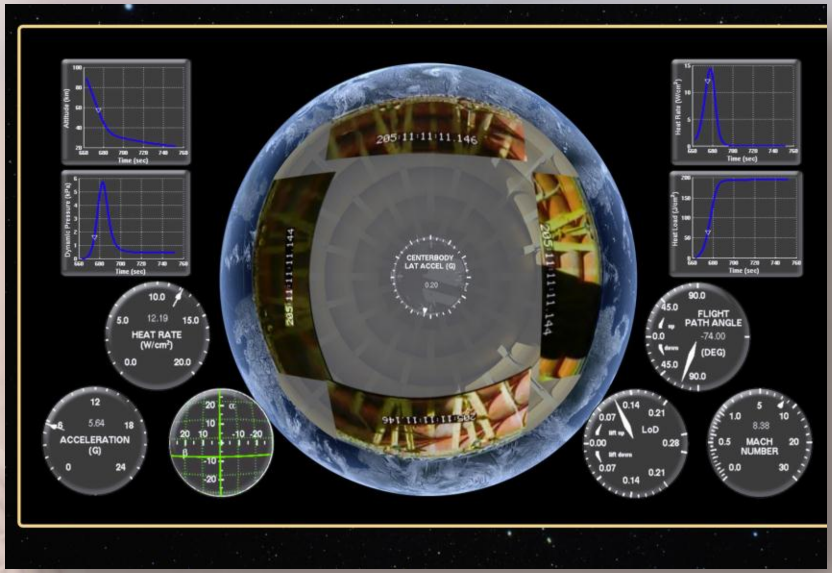


Scalloped OML heating investigation 20in Mach 6 Air

IRVE-3 Flight



IRVE-3 Launch WFF
July 23, 2012



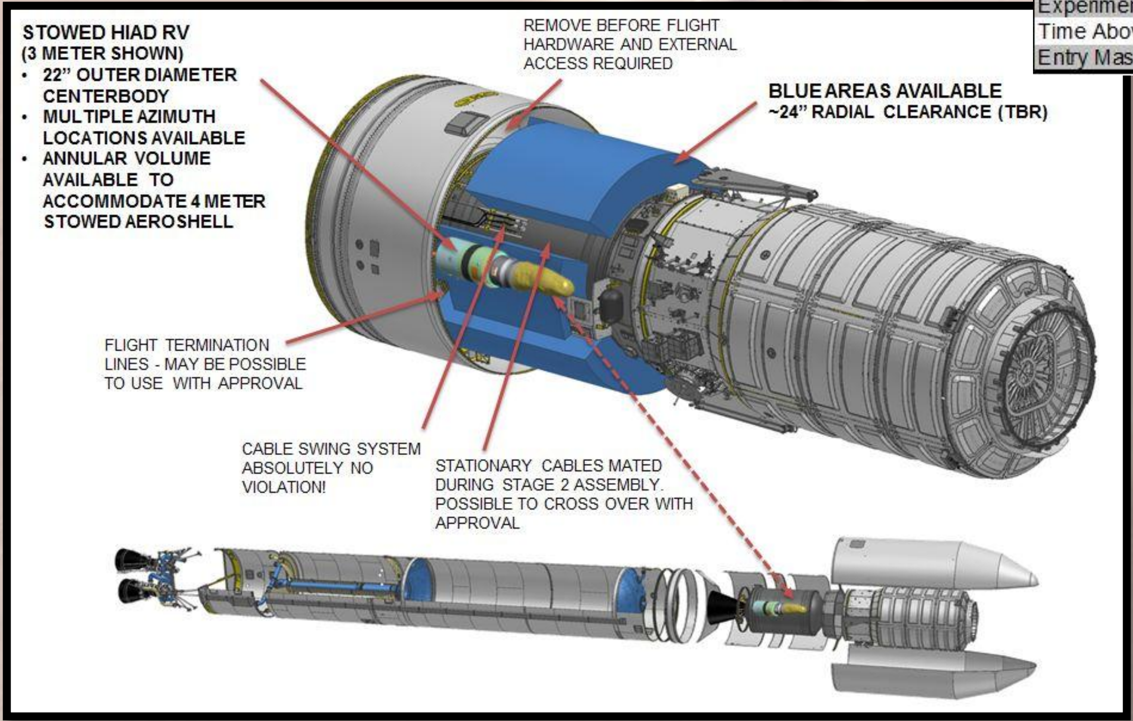
IRVE-3 Aft Camera Composite

- IRVE-3 had a fully successful flight
- Demonstrated lifting flight with a flexible aeroshell
- Vehicle was stable hypersonic through subsonic flight regime
- All data successfully received beyond nominal end of mission, even included additional maneuvers past end of mission

BTP Hardware

- Flight spare unit of the IRVE-3 centerbody hardware
  - Mitigation in the event of launch vehicle failure
  - With successful flight now available for mission
- Antares secondary payload
  - New launch vehicle option
  - Deliver orbital velocity reentry

	Antares 3m HIAD	Antares 4m HIAD
Apogee (km)	163.7	163.7
Entry Velocity (m/s)	7536.9	7534.6
Max Mach Number	26.8	26.7
Entry Flight Path Angle (deg)	-0.39	-0.39
Peak Heat Flux (W/cm^2)	47.8	40.0
Total Heat Load (kJ/cm^2)	11.3	9.3
Peak Dynamic Pressure (kPa)	1.9	1.4
Peak Acceleration (g)	6.4	6.8
Experiment Duration (sec)	817.4	757.5
Time Above 2 W/cm^2 (sec)	719.3	659.4
Entry Mass (kg)	294	349



Summary/Next Steps

- HIAD has completed the technology maturation of our 1st generation aeroshell system and it is ready for mission infusion
  - System exceeded initial goals for 1st gen
    - >40W/cm^2 peak heating capability
    - >8kJ/cm^2 heat load capability
- HIAD has identified 2nd generation aeroshell materials that significantly improve 1st generation capabilities and coupon/element demonstration testing has begun
  - System exceeding initial goals for 2nd gen
    - >60W/cm^2 peak heating capability
    - >12kJ/cm^2 heat load capability
- Mission Apps trade studies have identified several mission types where HIAD technology is beneficial to the missions.
  - This FY complete a more detailed
- BTP hardware available for subscale mission in support of 2nd generation aeroshell
- Unfortunately, budget uncertainties endanger all future HIAD technology development.